Arid Soil Research and Rehabilitation, Volume 6, pp. 105-116
Printed in the UK.

0890-3069/92 $3.00 + .00

Aspect and Species Influences on Nitrogen and Phosphorus Accumulation in Arizona Chaparral Soil–Plant Systems

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Abstract *To improve understanding of nutrient relationships and factors affecting nutrient patterns in chaparral ecosystems a study was conducted to quantify the effect of aspect and shrub species on accumulation of N and P in a mature chaparral ecosystem. Components of shrub biomass, litter, and soil were sampled from 32 randomly selected soil–plant systems, eight each of* Cercocarpus betuloides *and* Quercus turbinella *on north and south aspects, and analyzed for N and P. Shrub species influenced dry matter accumulation, with* Cercocarpus *accumulating more biomass in leaves, stems, and litter than* Quercus. *Similarly, N concentration and accumulation were greater in* Cercocarpus *systems than in* Quercus *systems. This was attributed to the ability of* Cercocarpus *to form symbiotic relationships with actinomycetes capable of N fixation. Phosphorus accumulation was much greater in* Cercocarpus *biomass than in* Quercus. *Aspect significantly influenced P concentration of soil, with higher concentrations occurring on north than south aspects, which are subject to higher rates of erosion. About 40% of total N and 15% of total P in these systems are in the biomass, litter, and soil (0–2 cm); hence, the systems are especially vulnerable to loss by volatilization during prescribed fire or wildfire, and from erosion.*

Keywords: *Cercocarpus betuloides, Quercus turbinella*, birchleaf mountain mahogany, turbinella oak, nitrogen fixation, nutrient cycling

Introduction

The chaparral ecosystem covers extensive areas of the southwestern United States including 1.3×10^6 ha in Arizona (Bolander 1982). Watersheds supporting chaparral vegetation serve as water sources for many cities and serve as valuable wildlife habitat; hence, successful management of these systems is of practical importance. Knowledge of soil–plant–nutrient relationships for chaparral is fragmented and sketchy. Research has been directed chiefly at the California chaparral, much of it focused on N status of the soil–plant system, including mechanisms of loss and replenishment (DeBano and Conrad 1978, DeBano et al. 1979, Dunn and Poth 1979, Dunn et al. 1979, Schlesinger

Received: September 20, 1991; accepted: October 8, 1991.
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and Hasey 1981, Marion and Black 1988). However, P also merits attention because it is occasionally deficient (Hellmers et al. 1955, McMasters et al. 1982), it is susceptible to loss by erosion and volatilization from chaparral soils under certain burn conditions (Harwood and Jackson 1975, DeBano and Conrad 1978), and it plays an important role in accumulation of N and organic carbon in soil–plant systems (Cole and Heil 1981, Stevenson 1986).

Many studies, especially those dealing with soils underlying trees and shrubs in arid and semiarid environments, have shown that biotic factors can significantly influence chemical and physical properties of soils, and that these influences are commonly species dependent (Fireman and Hayward 1952, Zinke 1962, Charley and West 1975, Lodhi 1977, Barth and Klemmedson 1978, Klemmedson and Tiedemann 1986). The influences of topography on soil–plant systems are well known to ecologists and land managers and can be attributed to differences in microclimate and insolation that are related to topography. The influences of aspect on organic properties of soil–plant systems are usually quite marked (Aandahl 1949, Klemmedson 1964, Jenny 1980).

The purpose of the present study was to assess the effect of biota and aspect on N and P accumulation in soil–plant systems of a chaparral watershed. The null hypothesis was that differences in shrub species (*Cercocarpus betuloides* Nutt. versus *Quercus turbinella* Greene) and aspect (north versus south) have no significant effect on the N and P status of the ecosystem studied.

Methods

Study Area

The study area was within a 55-ha drainage of the Battle Flat Watershed in the Bradshaw Mountains of central Arizona (34°19′N, 112°22′W). The topography is rough and highly dissected. Most of the watershed faces southeast; slope gradient ranges from 8 to 30°. Altitude is about 1700 to 1770 m above sea level. Geologic parent material of this site is massive bedded crystalline tuff with recent gravels along stream beds (Anderson and Blacet 1972). The Moano very rocky loam soils common to the study site are classified as Lithic Ustorthents (Humbert et al. 1981).

The dense shrubby vegetation averages about 75–80% crown cover. Canopy height varies from 1 to 3 m; shrub height and cover are greatest on northerly aspects. Dominant shrubs are *Arctostaphylos pungens* H. B. K., *Quercus turbinella*, and *Cercocarpus betuloides*. Subdominant shrubs include *Quercus emoryi* Torr., *Juniperus deppeana* Steud., *Ceanothus greggii* Gray, *Fallugia paradoxa* (D. Don) Endl., and *Eriodictyon angustifolium* Nutt. The herbaceous understory is sparse. In 1985 when this study was initiated the stand of vegetation occupying the Battle Flat Watershed was 85–90 years old, having last burned around the turn of the century (Deiterich and Hibbert 1990).

At Battle Flat the mean annual precipitation of 48 cm is about equally divided between cyclonic winter and convective summer storms. About 15–20% of total precipitation is snow. Mean daily temperature is 15 °C; mean minimum and maximum temperatures are 13 and 35 °C, respectively. Southerly aspects receive a great deal more insolation than do northerly aspects resulting in soils from south aspects exhibiting higher temperatures and lower soil moisture contents than soils from north aspects (Griffin 1973, Barbour et al. 1980). In general, soil temperature and moisture conditions of soils from north aspects favor accumulation of nutrients (Klemmedson 1964), breakdown of

*Taxonomy follows Kearney and Peebles (1960).

litter (Fogel and Cromack 1977), and mineralization of nutrients in litter and soil organic matter (Cassman and Munns 1980).

Conceptual Model

The conceptual model was based on a formalistic approach to ecological research developed by Jenny (1961) and Major (1951). The model

$$N, P = f(o_s, r_a)_{cl,o,r,p,t} \tag{1}$$

states that N and P accumulation are a function of species of shrub (o_s) occupying the site and topographic aspect (r_a) when climate (cl), biotic factors other than species (o), topography other than aspect (r), parent material (p), and age of the soil–plant system (t) are held constant or nearly so. Using this model, we carried out an observational study (Cochran 1983) of field sampling with rigid control of extraneous variation that satisfied the criteria for testing the hypothesis.

Implementation of Model

Two shrub species, *C. betuloides* and *Q. turbinella*, were chosen for sampling to express o_s and two aspects, north and south, were chosen for sampling to express r_a in the test of hypothesis. We randomly selected 32 shrubs, eight of each species on each aspect, from a pool of 80 mature shrubs that were widely distributed among lateral drainage channels feeding the main drainage. Each of the 80 shrubs was selected to control within narrow limits variation associated with the invariant factors in equation 1. This was done to assure that variation in those factors could be expected to have a negligible effect on the dependent variable.

Climate was invariant within the small study area. Because the 32 soil profiles displayed no differences in maturity and because only mature shrubs were considered, differences in time of soil–plant system development also were negligible. Only one geologic parent material is described for the study area (Anderson and Blacet 1972), and field inspection disclosed no discernible parent material differences. No evidence was found that the human aspect of the biotic factor, including grazing, use of fire, or other human activities leading to differential impact, including erosion, within the drainage, had been other than random within the study area. Differences in plant density, understory vegetation, and microflora were assumed to be associated primarily with aspect and cover differences; hence, these potential differences were expected to show up as effects of aspect or shrub species.

Sampling and Analysis

In October 1985, after the current year's growth was complete and prior to leaf abscission, shrub dimensions (shrub height, stem diameter, and canopy diameter) were measured and representative samples (approximately 100 g) of leaves and annual and secondary growth were collected from each shrub for determination of N and P content. Biomass of shrubs and their components (leaves, annual and secondary growth) was estimated using the measured shrub dimensions as input variables for allometric equations developed and validated at the study area (McCraw 1985). The organic horizon and soil were sampled in plots centered midway between the main stem and the canopy edge on the up-slope side of each shrub. The entire organic horizon was collected from a 25- × 50-cm plot. Samples of the 0- to 2-cm and 2- to 10-cm mineral soil layers were collected from soil columns on all plots. The 10- to 30-cm layer was collected from half of the plots. Horizontal dimensions of these samples were recorded to permit expression of soil nutrients on a mass/volume basis. Depth to bedrock was highly variable; it was often encountered at less than 20 cm.

Plant samples were oven-dried (70 °C), weighed, and ground to pass through a 425-μm sieve. Soils were air-dried, sieved to remove the >2-mm fraction, then ground to pass through a 150-μm sieve. Plant and soil samples were analyzed for organic C by dry combustion (Nelson and Sommers 1982) in a Leco high-frequency induction furnace. Total N was determined by the semi-micro-Kjeldahl method (Bremner and Mulvaney 1982). Total P was determined using the vanado-molybdo-phosphoric yellow color method after dry ashing of plant samples and the ammonium-molybdo-phosphoric blue color method following Na_2CO_3 fusion of soils (Jackson 1958).

Data were analyzed using two-way analysis of variance appropriate for a randomized design. Shrub species (*Cercocarpus* versus *Quercus*) and aspect (north versus south) were considered fixed treatments with two levels within each treatment. The eight samples in each species–aspect combination provided a sample size of 32 observations allowing us to test the main effects (species and aspect) and the species by aspect interaction using an error term with 28 degrees of freedom (Cochran 1983).

Results

Dry Matter

Shrub species significantly influenced dry matter accumulation for every biomass component except leaves and litter (Table 1). *Cercocarpus* accumulated larger biomass in each of these components and for the total system than did *Quercus*. By contrast, aspect had no influence on dry matter accumulation. This was surprising. Based on observation and travel through the stands, it was obvious that shrubs were taller, and it appeared that canopy cover and areal biomass were greater on north than south aspects. On northerly aspects *Quercus* shrubs averaged 2.28 m in height and 1.85 m^2 in canopy area and *Cercocarpus* shrubs averaged 3.04 m in height and 6.08 m^2 in canopy area. On southerly

Table 1
Dry Matter Distribution in *Cercocarpus betuloides* and *Quercus turbinella* Soil–Plant Systems from an Arizona Chaparral Watershed

Component	*Cercocarpus* (kg m^{-2})	*Quercus* (kg m^{-2})
Leaves	0.20 ± 0.06	0.10 ± 0.01 NS
Stems	2.05 ± 0.41	0.96 ± 0.08*
Standing crop	2.25 ± 0.46	1.06 ± 0.09*
Litter	4.11 ± 0.56	2.78 ± 0.41 NS
Total dry matter	6.36 ± 0.74	3.84 ± 0.43**

Note. Values are means ± SE; *$p < .05$, **$p < .01$; NS, not significant; $n = 16$.

Table 2
Concentration of Nitrogen in Components of *Cercocarpus betuloides* and *Quercus turbinella* Soil–Plant Systems as a Function of Shrub Species and Aspect

	Cercocarpus (g kg^{-1})		*Quercus* (g kg^{-1})	
Component	North	South	North	South
Standing crop				
Leaves	16.7 ± 0.7 a	17.8 ± 0.4 a	15.4 ± 0.5 b	14.3 ± 0.4 b
Stems				
Current	13.5 ± 0.6 a	13.3 ± 0.4 a	6.5 ± 0.2 c	8.5 ± 0.2 b
Older	9.2 ± 0.4 a	8.4 ± 0.4 a	5.1 ± 0.2 b	6.3 ± 0.2 b
Litter				
Leaves	13.0 ± 0.9 a	12.0 ± 1.2 a	10.1 ± 1.1 b	9.7 ± 1.2 b
Stems	9.5 ± 1.5 a	8.8 ± 0.9 a	6.4 ± 0.3 a	8.7 ± 1.2 a
Soil				
0–2 cm	6.6 ± 1.4 a	4.2 ± 1.0 a	5.0 ± 0.8 a	4.7 ± 0.9 a
2–10 cm	1.9 ± 0.3 a	1.4 ± 0.1 a	1.8 ± 0.5 a	1.9 ± 0.2 a
10–30 cm[a]	0.8 ± 0.2 a	0.6 ± 0.1 a	0.9 ± 0.2 a	0.5 ± 0.1 a

Note. Values are means ± SE; $n = 8$. Values within a row followed by the same letter are not significantly different by LSD ($p < .05$).
[a]$n = 4$.

aspects *Quercus* shrubs averaged 1.88 m in height and 1.05 m^2 in canopy area and *Cercocarpus* shrubs averaged 2.57 m in height and 5.46 m^2 in canopy area. These observations and our biomass data (Table 1) suggest that the growth forms of these two species differ with aspect. Shrubs occupying north aspects develop larger, more diffuse canopies, while those occupying south aspects develop smaller, more compact canopies. The net effect was that biomass production on an areal basis was not significantly different between aspects.

Nitrogen

Shrub species significantly influenced N concentration of all biomass components except stem litter, while aspect affected N concentration only in the current growth (Table 2). For each biomass component, N percentage was higher in *Cercocarpus* than in *Quercus*. We attribute this to N fixation in *Cercocarpus*. We have collected nodules from roots of *Cercocarpus* shrubs growing at Battle Flat and laboratory studies (Wienhold and Klemmedson 1991) suggest that under favorable moisture, temperature, and nutrient conditions this actinorhizal shrub is capable of fixing significant amounts of N. In a chaparral chronosequence of southern California, Marion and Black (1988) attributed increased soil N accretion to the presence of *Ceanothus greggii*, which is also an actinorhizal shrub. Other reports (Delwiche et al. 1965, Vlamis et al. 1971, Dunn and Poth 1979) document the contribution of N fixed by symbiotic organisms associated with herbs and shrubs of the chaparral type.

For all biomass components except litter, the species by aspect interaction was significant. This was caused by differential aspect effects between species. In some cases, aspect affected N percentage in one species but not the other (e.g., current stems), or the aspect effect was reversed between species (e.g., older stems and stem litter, Table 2). Species and aspect had no effect on N concentration of soils. Lack of a significant aspect effect on N concentration of soil was not expected and was highly unusual in view of the ubiquitous observation of higher N concentration of soils on north aspects in the northern hemisphere (Aandahl 1949, Klemmedson 1964, Jenny 1980).

Cercocarpus accumulated significantly greater amounts of N in all biomass components of its soil–plant system than *Quercus* (Table 3). The species difference was especially noted in stems. Greater N in leaves is associated with higher N concentration of leaves (Table 2), while greater amounts of stem N are a function of both greater mass of stems (Table 1) and higher N concentration of stems in *Cercocarpus* (Table 2). Influence of the shrub did not carry through to the soil since there were no significant differences in N content of soil under these two species. Nor did we detect an influence of aspect on amount of N in these soil–plant systems.

The allocation of N within the soil–plant system differed with species (Table 3). *Cercocarpus* accumulated a greater percentage of ecosystem N in the standing crop (7.6 versus 2.8%) and litter (16.8 versus 11.4%), while *Quercus* accumulated a larger percentage of total N in the soil (Table 3). These differences appear consistent with concentration and dry matter differences between the species noted above.

Phosphorus

Shrub species only weakly influenced P concentration of system components (Table 4). Older stems and leaf litter of *Cercocarpus* were slightly higher in P concentration than those of *Quercus*; P concentration of other system components was unaffected by spe-

Table 3
Amount and Distribution of Nitrogen in *Cercocarpus betuloides* and *Quercus turbinella* Soil–Plant Systems from an Arizona Chaparral Watershed

	Cercocarpus		*Quercus*	
Component	g m^{-2}	%	g m^{-2}	%
Leaves	3.5 ± 1.1	1.2	1.5 ± 0.1	0.6*
Stems	18.8 ± 4.7	6.4	5.6 ± 0.5	2.2**
Standing crop	22.3 ± 5.7	7.6	7.0 ± 0.6	2.8*
Litter	49.8 ± 6.7	16.8	29.1 ± 5.9	11.4*
Soil				
0–2 cm	58.3 ± 7.6	19.7	52.7 ± 5.5	20.6 NS
2–10 cm	91.6 ± 10.2	31.9	79.2 ± 12.5	30.9 NS
10–30 cm[a]	73.9 ± 10.9	25.0	87.7 ± 11.8	34.3 NS
Subtotal	223.8	75.6	219.6	85.8 NS
Total	295.9	100.0	255.8	100.0 NS

Note. Values are means ± SE; $^{*}p < .05$, $^{**}p < .01$; NS, not significant; $n = 16$.
[a]$n = 8$.

Table 4
Concentration of Phosphorus in *Cercocarpus betuloides* and *Quercus turbinella* Soil–Plant Systems as a Function of Species and Aspect

	Cercocarpus (mg g^{-1})		*Quercus* (mg g^{-1})	
Component	North	South	North	South
Standing crop				
Leaves	1.02 ± 0.02 a	0.89 ± 0.06 b	1.04 ± 0.07 a	0.91 ± 0.07 b
Stems				
Current	0.78 ± 0.07 a	0.84 ± 0.06 a	0.73 ± 0.06 a	0.87 ± 0.11 a
Older	0.52 ± 0.05 a	0.56 ± 0.05 a	0.43 ± 0.04 a	0.48 ± 0.04 a
Litter				
Leaves	0.82 ± 0.06 a	0.66 ± 0.06 b	0.77 ± 0.04 a	0.48 ± 0.08 b
Stems	0.48 ± 0.07 a	0.39 ± 0.06 a	0.41 ± 0.02 a	0.51 ± 0.06 a
Soil				
0–2 cm	0.54 ± 0.05 a	0.30 ± 0.06 b	0.58 ± 0.05 a	0.46 ± 0.11 b
2–10 cm	0.49 ± 0.04 a	0.16 ± 0.02 c	0.44 ± 0.05 a	0.31 ± 0.03 b
10–30 cm[a]	0.34 ± 0.08 a	0.11 ± 0.02 b	0.30 ± 0.05 a	0.17 ± 0.02 b

Note. Values are means ± SE; $n = 8$. Values within a row followed by the same letter are not significantly different by LSD ($p < .05$).
[a] $n = 4$.

cies. The effect of aspect on P concentration was noted in all components except stems and stem litter. Leaves on north-facing slopes averaged 14% more P than those on south-facing slopes, while leaf litter on north-facing slopes was 40% higher in P than that on south-facing slopes. Stem litter of *Quercus* systems on south-facing slopes was higher in P than that on north-facing slopes; this exposure pattern is the reverse of that found for *Cercocarpus* and explains the significant species by aspect interaction for stem litter (Table 4).

All soil layers, even the 10- to 30-cm layer, on northerly aspects were significantly higher in P concentration than those of southerly aspects (Table 4). The significant species by aspect interaction for the 2- to 10-cm soil layer is explained by the much greater difference in P concentration of this soil layer between aspects for *Cercocarpus* systems than for *Quercus* systems.

The influence of shrub species and aspect on P accumulation in these soil–plant systems differed from that for N. *Cercocarpus* systems contained significantly more P in stems, litter, and standing crop than did *Quercus* systems (Table 5). Leaves of the two species did not differ in P content. *Cercocarpus* contained 83% more P in its biomass than *Quercus*. Moreover, *Cercocarpus* biomass contained over twice as much of the system P (9.2 versus 4.2%) as did *Quercus* biomass. Species influenced soil P accumulation only in the 10- to 30-cm layer (Table 6), with one-third more P under *Quercus* than *Cercocarpus* in this layer. This represented about 54% of total P in the *Quercus* soil–plant systems compared with about 44% in *Cercocarpus* systems. This was a surprising result; we would expect to see species effects manifested in the surface, rather than in subsoil layers.

Table 5
Amount and Distribution of Total Phosphorus in Biomass Components of *Cercocarpus betuloides* and *Quercus turbinella* from an Arizona Chaparral Watershed

	Cercocarpus		*Quercus*	
Component	g m^{-2}	%	g m^{-2}	%
Leaves	0.19 ± 0.06	0.4	0.10 ± 0.01	0.2 NS
Stems	1.14 ± 0.25	2.5	0.44 ± 0.04	0.8*
Standing crop	1.33 ± 0.30	2.9	0.54 ± 0.05	1.0*
Litter	2.92 ± 0.39	6.3	1.78 ± 0.35	3.2*
Total biomass	4.25	9.2	2.32	4.2**

Note. Values are means ± SE; *$p < .05$, **$p < .01$; NS, not significant; $n = 16$.

Resembling N, the amount of P in the biomass was not affected by aspect. Unlike N, aspect strongly ($p < .01$) influenced the amount of P in the 2- to 10- and 10- to 30-cm soil layers; north aspect soils contained more P than south aspect soils. That soil from the 0- to 2-cm layer of north aspects did not contain more P, despite significantly higher concentration of P (Table 4), may be attributed to the high organic matter content (Table 7), and thus low bulk density, of this soil layer. From the standpoint of soil P distribution, some influence of aspect was apparent, but it differed among soil layers, probably because of the influence of organic matter on bulk density. In the 0- to 2-cm layer, soil from southerly aspects contained higher percentages of total system P than soil from northerly aspects (Table 6). By contrast, in the 2- to 10-cm soil layer, north aspects contained about 10% more of the soil–plant system P than south aspects.

Because of the significant effect of aspect on soil P, both in concentration and amount of P, and especially in the 10- to 30-cm layer, we suspected that parent material may have been confounded with aspect, i.e., that there actually were differences in

Table 6
Amount and Distribution of Total Phosphorus in Soil Collected Under *Cercocarpus betuloides* and *Quercus turbinella* Shrubs in an Arizona Chaparral Watershed

	Cercocarpus				*Quercus*			
	North		South		North		South	
Soil Layer	g m^{-2}	%	g m^{-2}	%	g m^{-2}	%	g m^{-2}	%
0–2 cm	3.7 ± 0.5 a	6	4.6 ± 0.7 a	14	5.8 ± 0.6 a	9	5.9 ± 1.0 a	15
2–10 cm	25.1 ± 1.5 a	43	10.5 ± 1.1 b	31	21.7 ± 1.8 a	36	9.5 ± 1.3 b	24
10–30 cm[a]	24.9 ± 3.3 b	43	14.9 ± 1.9 d	44	33.3 ± 3.5 a	53	21.2 ± 2.9 c	54

Note. Values are means ± SE; $n = 8$. Values within a row followed by the same letter are not significantly different by LSD ($p < .05$).
[a]n = 4.

Table 7
Concentration of Soil Organic Carbon in *Cercocarpus betuloides* and *Quercus turbinella* Chaparral Soil as a Function of Species and Aspect

	Cercocarpus (g kg^{-1})		*Quercus* (g kg^{-1})	
Soil Layer	North	South	North	South
0–2 cm	158.6 ± 18.3 a	64.8 ± 21.2 b	130.2 ± 33.5 a	60.3 ± 33.3 b
2–10 cm	32.4 ± 8.3 a	12.8 ± 3.0 b	51.6 ± 22.4 a	33.3 ± 9.8 a
10–30 cm[a]	10.4 ± 1.8 a	9.7 ± 1.3 b	12.6 ± 1.7 a	6.9 ± 1.6 b

Note. Values are means ± SE; $n = 8$. Values within a row followed by the same letter are not significantly different by LSD ($p < .05$).
[a] $n = 4$.

parent material between north and south aspects that influenced P status of the soil–plant systems. We tested this hypothesis by collecting and analyzing parent material samples (10 from each aspect). Petrographic analysis of the samples (macroscopic and thin section) showed that the samples were similar. Their average mineralogical composition as well as variation among samples resembled the Spud Mountain volcanic rocks described by Anderson and Blacet (1972) for the study area. Chemical analysis showed that the difference in P concentration between aspects was not significant. Hence, parent material does not appear to be confounded with aspect.

Discussion and Conclusions

The similarity of parent material suggests that the reason for aspect differences in soil P (Table 6) is a long-standing pattern of differential erosion between the two slopes leading to relative P depletion on southerly aspects. In arid and semiarid regions differences in microclimate between north- and south-facing slopes has a marked effect on the rate of geomorphic processes (Branson et al. 1981). Southerly aspects are typically more open and have more exposed soil between shrubs than northerly aspects. These characteristics are accompanied by differences in surface runoff and erosion, resulting in soils that are shallower and have lower organic matter on south aspects than those on north aspects (Branson et al. 1981). As Hellmers et al. (1955) suggested for soil fertility problems in the San Gabriel mountains of southern California, these attributes of southerly aspects both contribute to and manifest higher erodibility, a cycle that we believe has led to lower soil P on the south slopes at Battle Flat. As Hellmers et al. (1955) put it in describing the south slopes of their study area, "the surface layer of soil is continuously being removed from the slopes, leaving a shallow residual soil mantle. This continuous removal . . . also eroded away the plant nutrients leaving a soil of low fertility."

Because *C. betuloides* and *Q. turbinella* are two of the dominant species in Arizona chaparral, results of this research have important implications for management of the chaparral type in Arizona. *Quercus* and *Cercocarpus* store significant amounts of N and P in aboveground biomass components, including litter and organic matter of the soil surface. Under certain burning conditions nutrients stored in these components may be lost by volatilization and particulate transfer during fire (Harwood and Jackson 1975, Raison et al. 1985). Soil erosion also increases after a burn (Pase and Lindenmuth 1971) resulting in further loss of nutrients from the system (DeBano and Conrad 1978). These effects and the fact that ecosystem P is not replenished from external sources as is N necessitate careful management decisions where P fertility of chaparral is low. Although the chaparral is a fire-adapted system, where wildfire can be expected, and prescribed fire can be a valuable tool to achieve certain management objectives, continued productivity of the ecosystem may hinge on how ecosystem P is managed.

Acknowledgments

Research was funded by Rocky Mountain Forest and Range Experiment Station Cooperative Agreement 28-K4-321, Journal Article Number 7200 of the Arizona Agriculture Experiment Station. Appreciation is gratefully extended to Joseph S. Schreiber, Jr., for petrographic analysis of rocks, Justine McNeil for assistance in laboratory analysis, and Leonard F. DeBano for critical review of the manuscript.

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